Measuring the Top Mass in the Dilepton Channel

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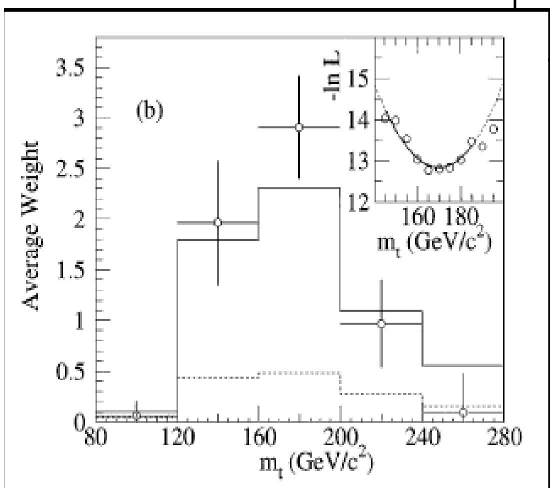
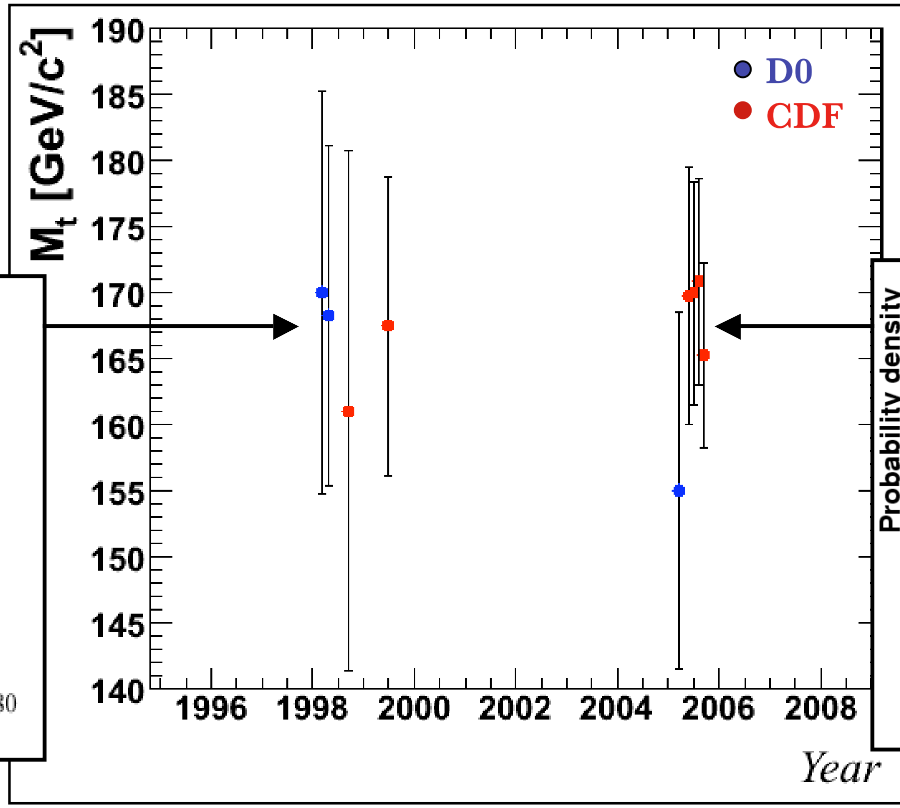
University of Pennsylvania

CDF/D0 Top Mass Worshop
October 11, 2005

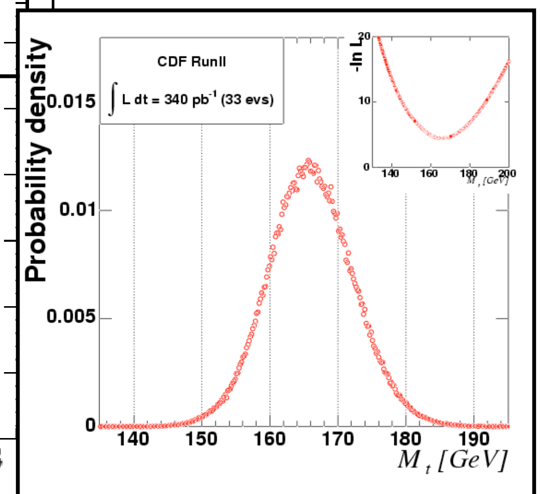
Dilepton History

1998: 6 events

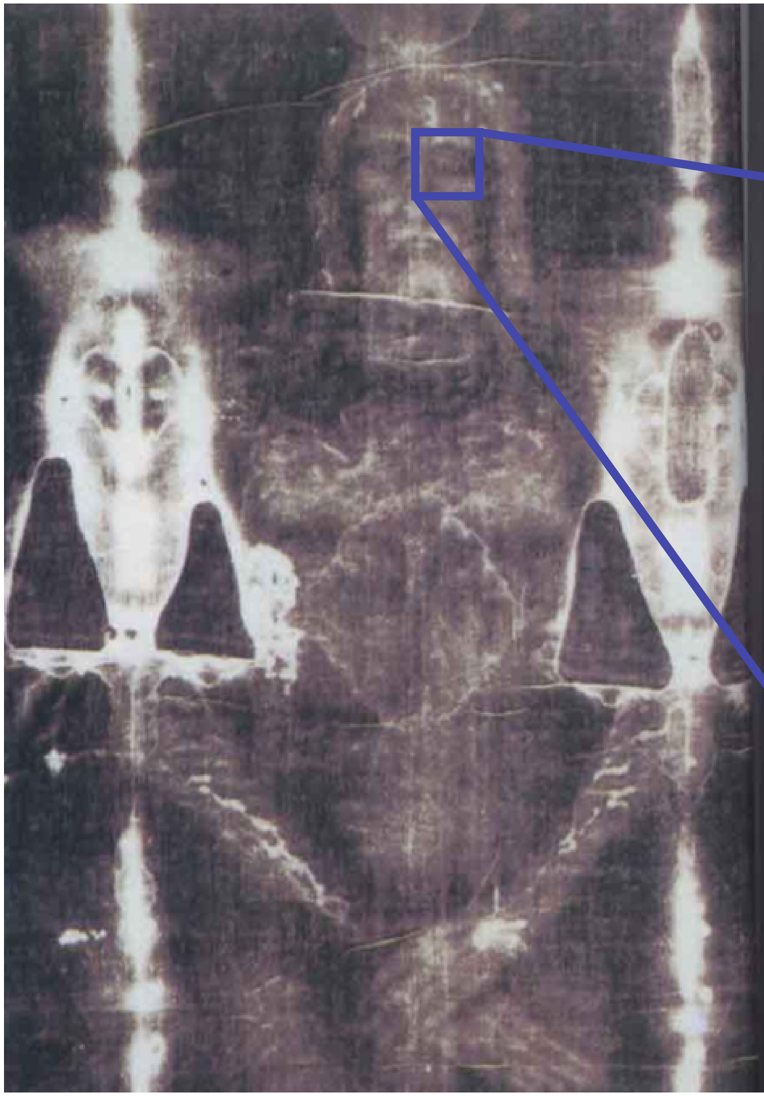




2005: 33 events

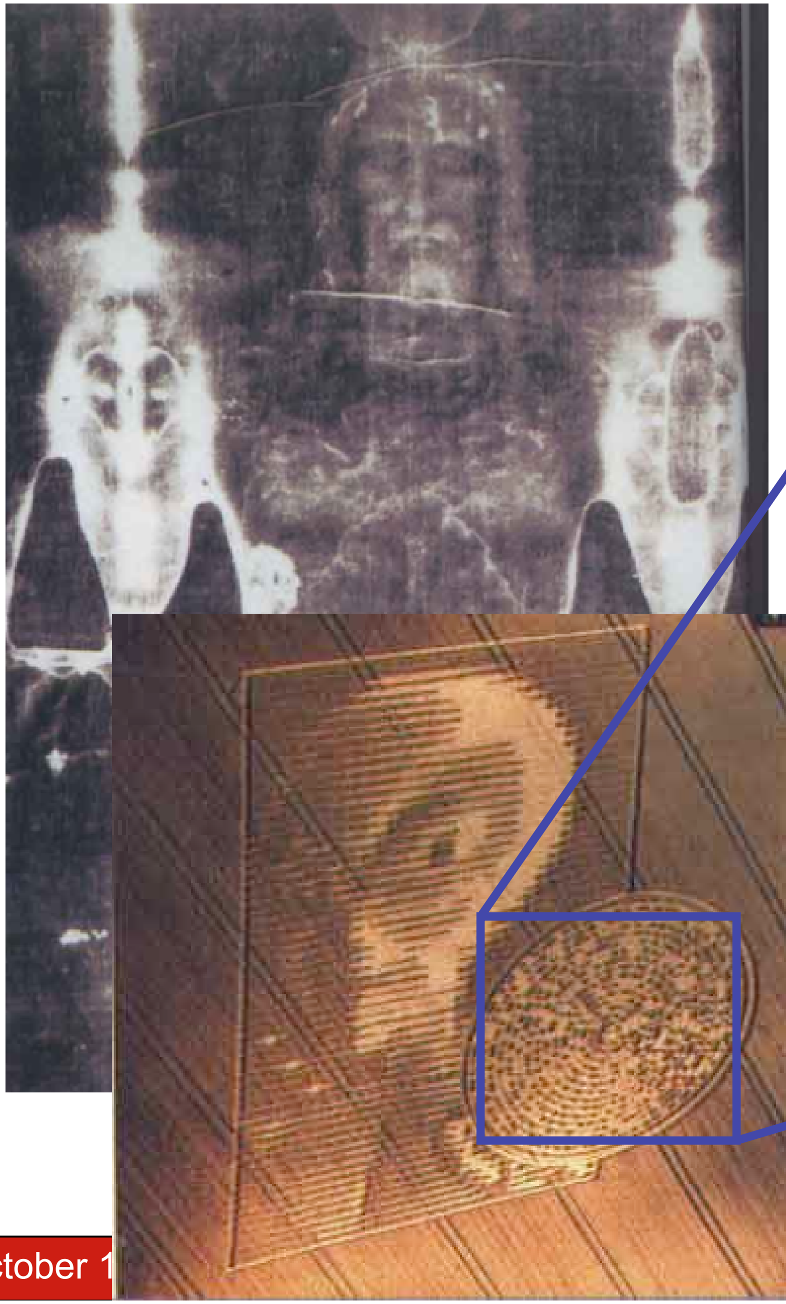


Dilepton History



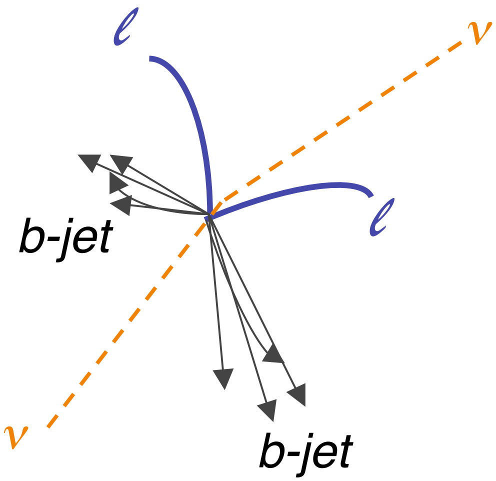
The "*Dilepton Lituus*", 29 BC

Dilepton History



The "*Dilepton Lituus*", 29 BC

Motivation



Advantages	*Disadvantages*
2 charged leptons	**2 neutrinos**
- good energy resolution	**- loss of information**
- reduce backgrounds	
Fewer jets	**No W jets**
- reduced dependence on jets	**- can't calibrates jets *in-situ***

Why measure dilepton mass?

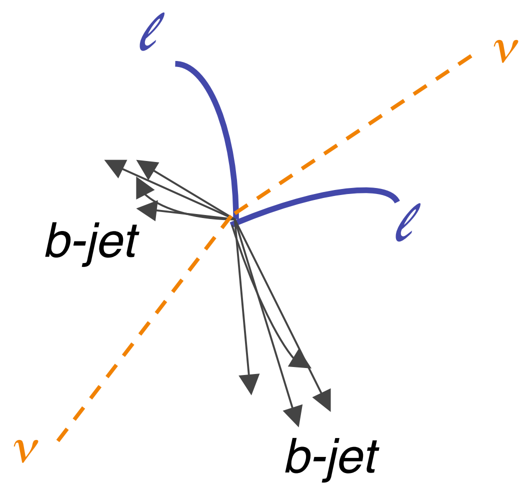
Potentially smaller systematics

Smaller statistics makes it a good place to use powerful methods

Comparison of mass in l+jets and dilepton channels

- ***aid understanding of systematics***
- ***sensitive to new physics***

The dilepton problem



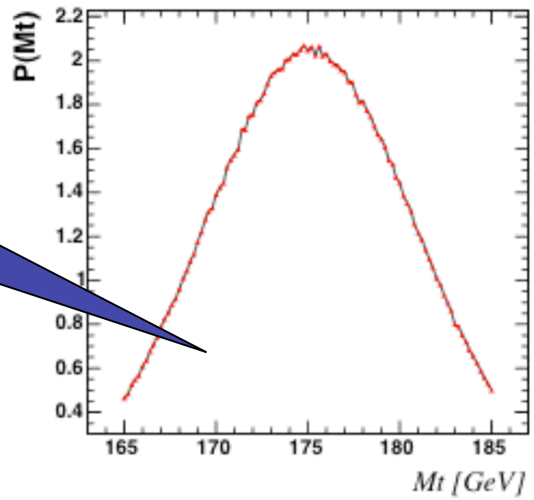
Information scarcity

No exact top mass in event - 4 pieces of information missing

Solution

Include full prior and integrate over unmeasured quantities.

Each event has a curve, rather than a single mass value



Construct probability curve $P(m_t \mid o)$ for each event o.

Form joint probability for sample, choose most probable value.

Dilepton Probability

From Varnes & Strovink (Varnes PhD Thesis, UC Berkeley, 1997)

P(m_t | o) is " proportional to the differential cross section into the region of phase space defined by the measured quantities and has the analytic form:

$$\mathcal{P} \propto \frac{1}{\sigma_{\text{vis}}(m_t)} \int |\mathcal{M}\{v_i\}|^2 \rho_1(o_1) \ldots \rho_{14}(o_{14}) \delta^4(m_i - M_i) d^{18}\{v_i\} \qquad (6.3)$$

$\mathcal{M}$ is a matrix element representing $t\bar{t}$ production and decay, the ρ's are normalized detector resolution functions, and the delta function enforces the W and top quark mass constraints on each side of the decay. "

Dilepton Probability

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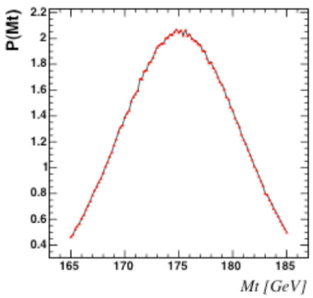
$\mathcal{M}$ is a matrix element representing $t\bar{t}$ production and decay, the ρ's are normalized detector resolution functions, and the delta function enforces the W and top quark mass constraints on each side of the decay. "

However,

"While Eq. 6.3 is exact, its solution is quite CPU-intensive. "

Strategy

$$\mathcal{P} \propto \frac{1}{\sigma_{\text{vis}}(m_t)} \int |\mathcal{M}\{v_i\}|^2 \rho_1(o_1)\ldots\rho_{14}(o_{14})\delta^4(m_i - M_i)d^{18}\{v_i\}$$



1. Approximate

- describe critical features
- parameterize where possible
- make assumptions where necessary

2. Correct

- calibrate using full simulation

Neutrino Weighting

D0 Run 1

*Assumptions:**

W's at pole mass

$M_t = M_t$

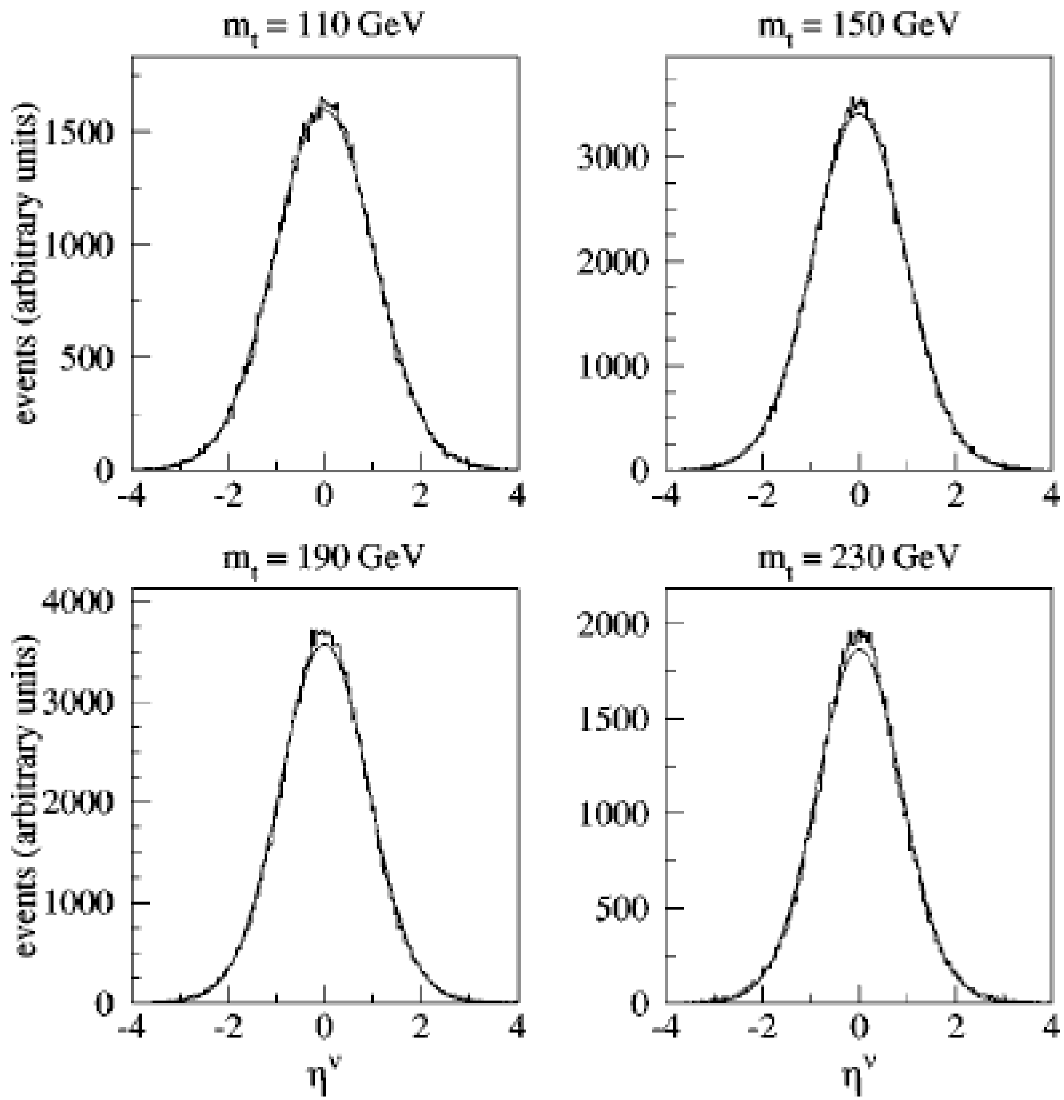
Approximations:

Prior for η of ν

parameterized as Gaussian

[Alternatively, $\mathcal{M}$ WT

describes decay angles]

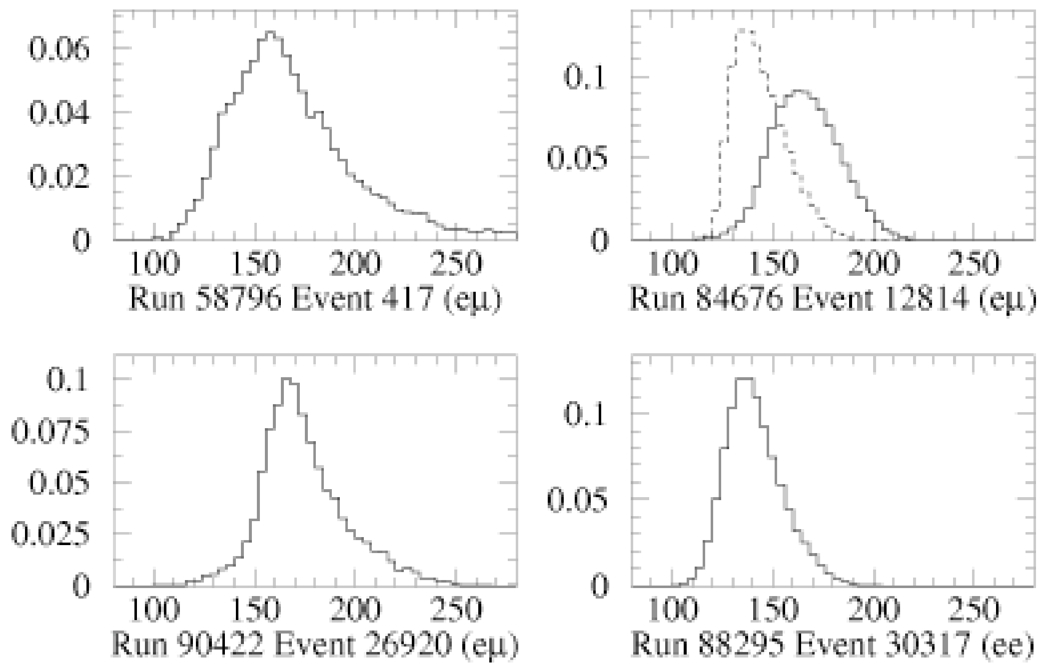


* Full list provided upon request

Neutrino Weighting
D0 Run 1

Integration
Probability is approximate
- **off-shell W and tops**
- **ISR/FSR**

Correlated with true prob
- **can't directly form joint prob**

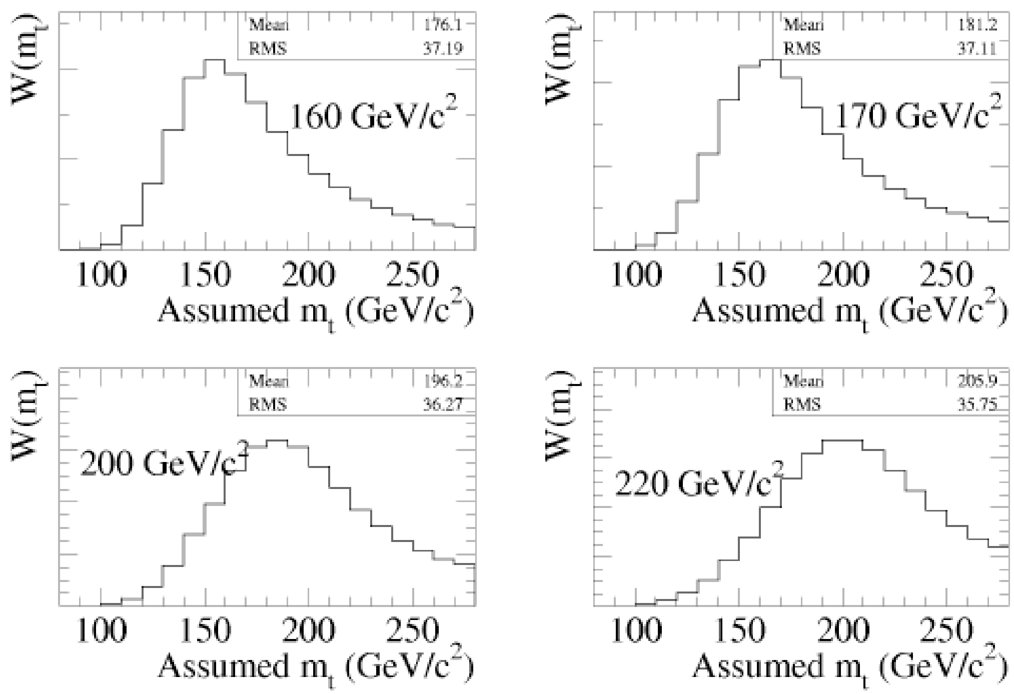


NeutrinoWeighting

D0 Run 1

Corrections

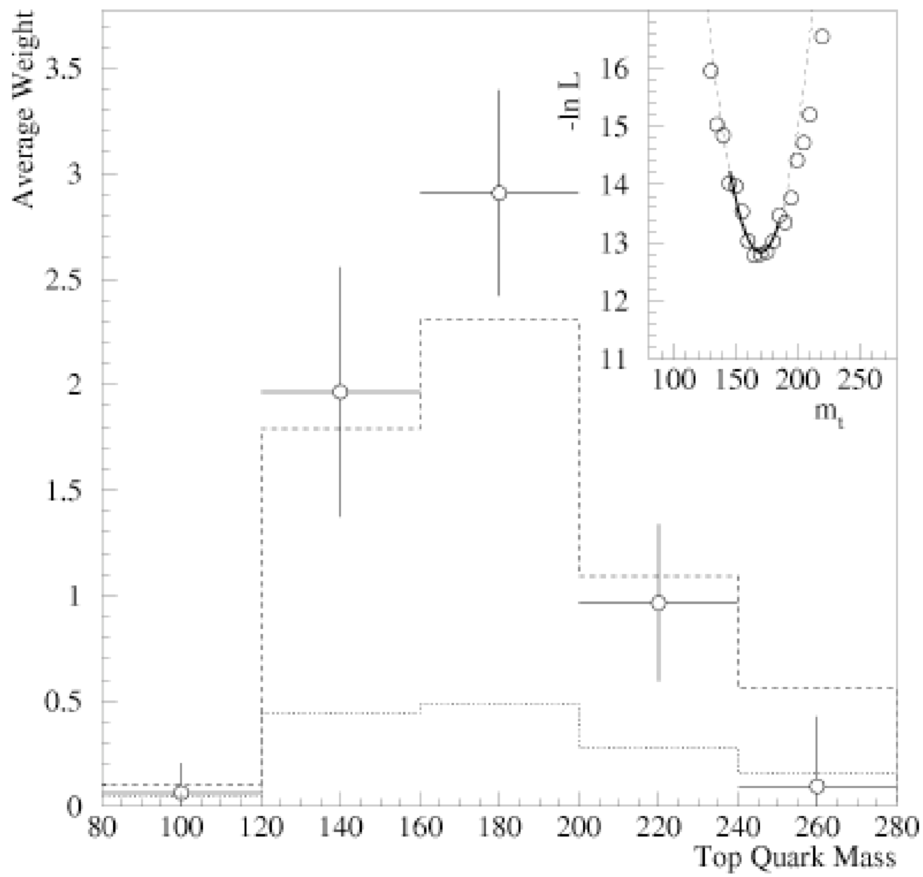
Compare response to that of full simulation



Behavior of result relies on description of performance of method in simulation.

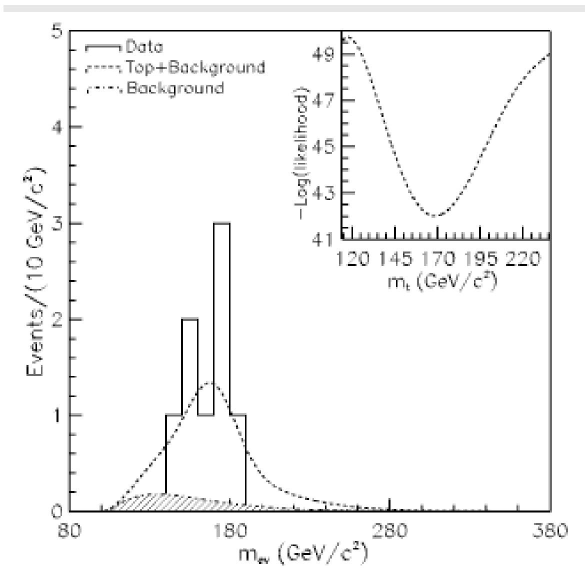
NeutrinoWeighting

D0 Run 1

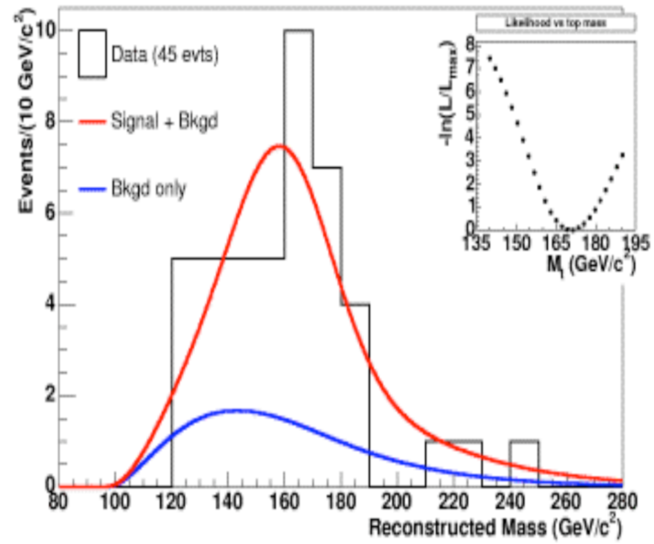


Final $P(M_t \mid x)$ **is not a direct calculation, but a parameterization [in 5 variables!]**

Applications of technique



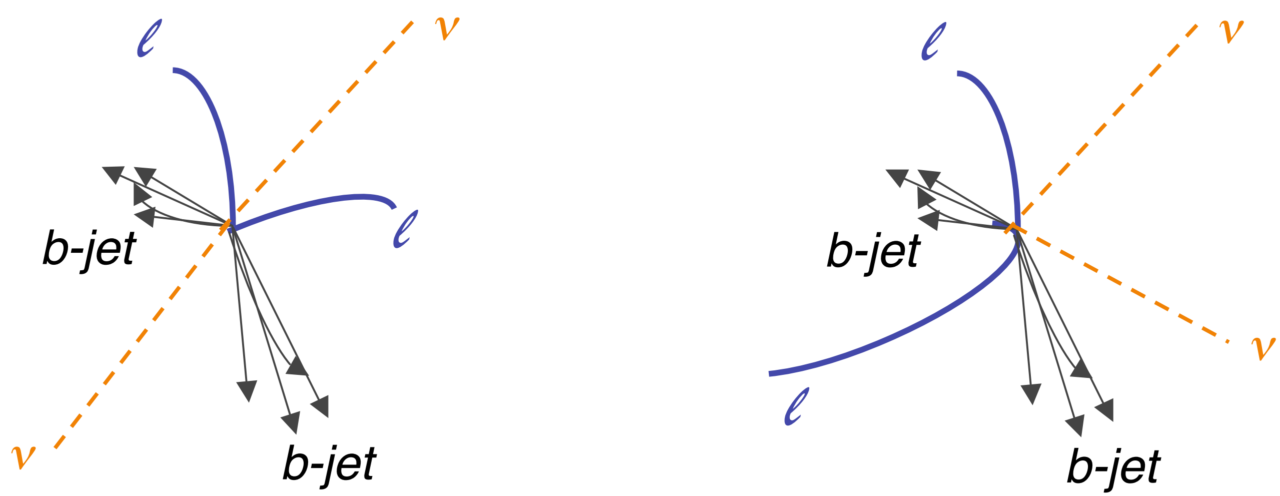
Phys. Rev. Lett. 82, 271 (1999)



Measurement	*Prior*	*Corrections*
D0 νWT	**Gaussian η of ν**	**5-Parameter Probability Density Estimates**
D0 $\mathcal{M}$ WT	**Simplified $\mathcal{M}$**	**5-Parameter Probability Density Estimates**
CDF νWT	**Gaussian η of ν**	**1-Parameter Parameterized Templates**
CDF φ of ν	**Flat ϕ of ν**	**1-Parameter Parameterized Templates**
CDF P_z of tt	**Gaussian P_z of tt**	**1-Parameter Parameterized Templates**

Dilepton events

All events are not created equal. Some have much more information than others.



***How to take advantage of this*?**

- relax kinematic assumptions

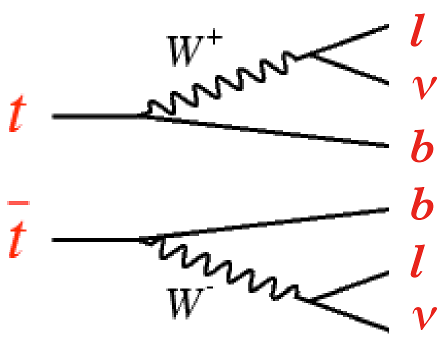
- integrate over priors (W, top masses) rather than fix values

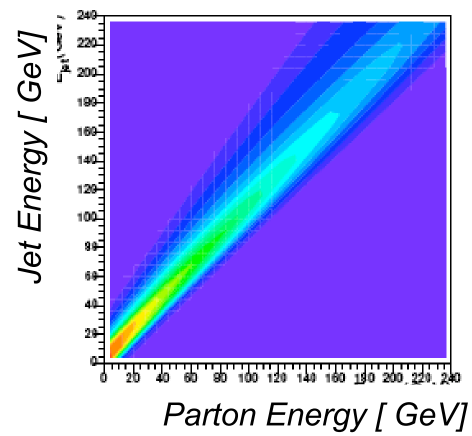
- directly multiply approximate probabilities

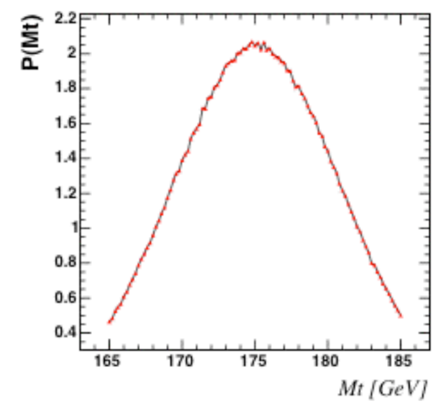
Matrix-element Method

Break into two pieces: parton-level process and showering/resolution effects

$$P(\textit{partons} \mid M_t) \quad \times \quad P(\textit{event o} \mid \textit{partons}) \quad = \quad P(\textit{event o} \mid M_t)$$







History

Paper by K. Kondo, *et. al.* [J. Phys. Soc. Japan **57** 4136 (1988)]

First measurement in Run1 by D0 in l+jets [Nature **429** 636 (2004)]

Applied in Run2 by CDF and D0 in l+jets [W&C 6/11/04 and 7/22/05]

Calculation

p 4-momentum of final partons
q 4-momentum of initial partons
o measured event variables

$$P(\mathbf{o}|M_t) = \frac{1}{N}\int d\Phi_6 |\mathcal{M}_{t\bar{t}}(p;M_t)|^2 \prod_{jets} f(p_i,\mathbf{o})\, f_{PDF}(q_1)\, f_{PDF}(q_2)$$

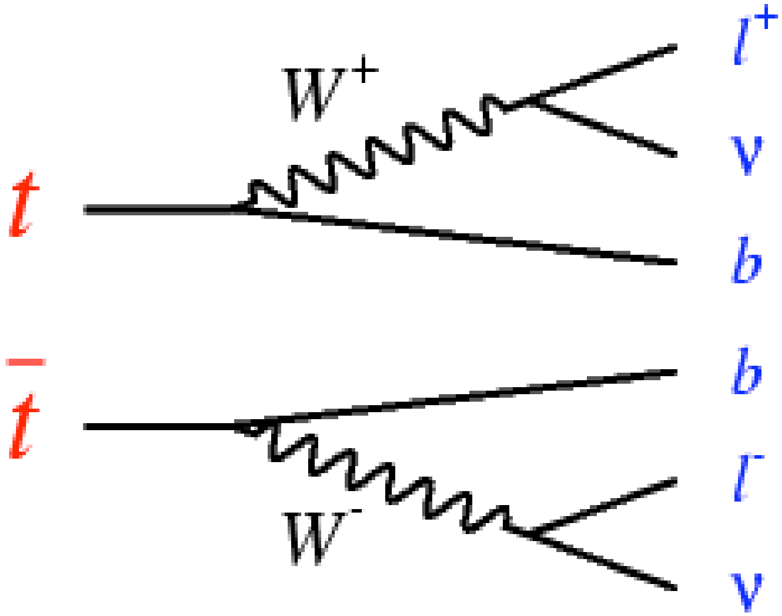
Phase-space Integral — **Matrix Element** — **Transfer Functions**

Only partial information available

Fix lepton momenta

Integrate over 6 unmeasured parton quantities consistent with *tt* production and measured event.

Unknowns



6 unknowns

3 (neutrino)

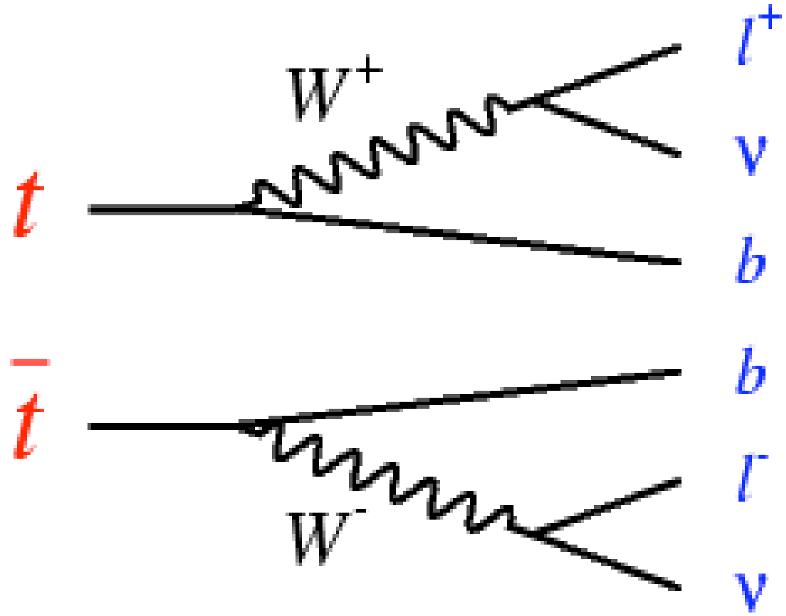
1 (quark energy)

1 (quark energy)

3 (neutrino)

-2 (P_T conservation)

Integration



6 unknowns	6 integration variables
3 (neutrino)	*W,t* invariant masses
1 (quark energy)	quark energy
1 (quark energy)	quark energy
3 (neutrino) *-2 (P_T conservation)*	*W,t* invariant masses

Choice of variables

Transform phase space to exchange variables for those which are more efficient.
Requires numerical solution at each integration point.
Integration done with VEGAS.

Background Likelihood

The probability can be generalized to a weighted sum of signal & bg probabilities

$$P(\mathbf{x}|M_t) = P_s(\mathbf{x}|M_t)p_s + P_{bg1}(\mathbf{x})p_{bg1} + P_{bg2}(\mathbf{x})p_{bg2}\ldots$$

Where the weights are the expected sample fraction:

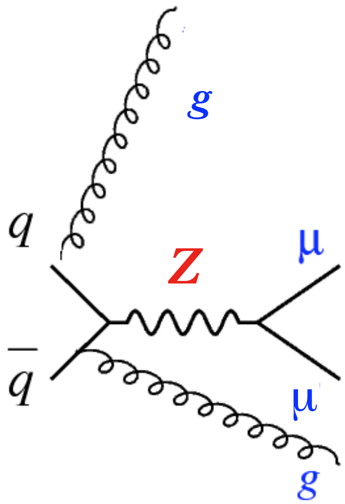
$$p_s(M_t) = \frac{\lambda_s(M_t)}{\lambda_s(M_t) + \lambda_b}$$

$$p_b = \frac{\lambda_b}{\lambda_s(M_t) + \lambda_b}$$

λ = expected number of events

One would prefer to constrain the sample fraction and fit for it rather than fix it.

Z+jets



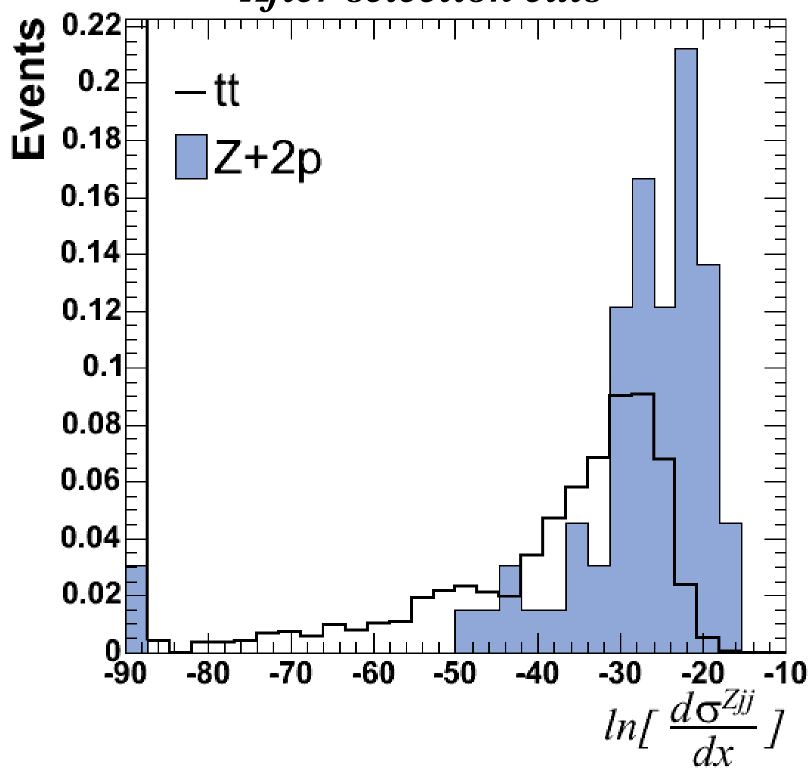
0 unknowns

1 parton energy

1 parton energy

-2 (*P_T conservation)*

After selection cuts



Matrix Element & Integrals

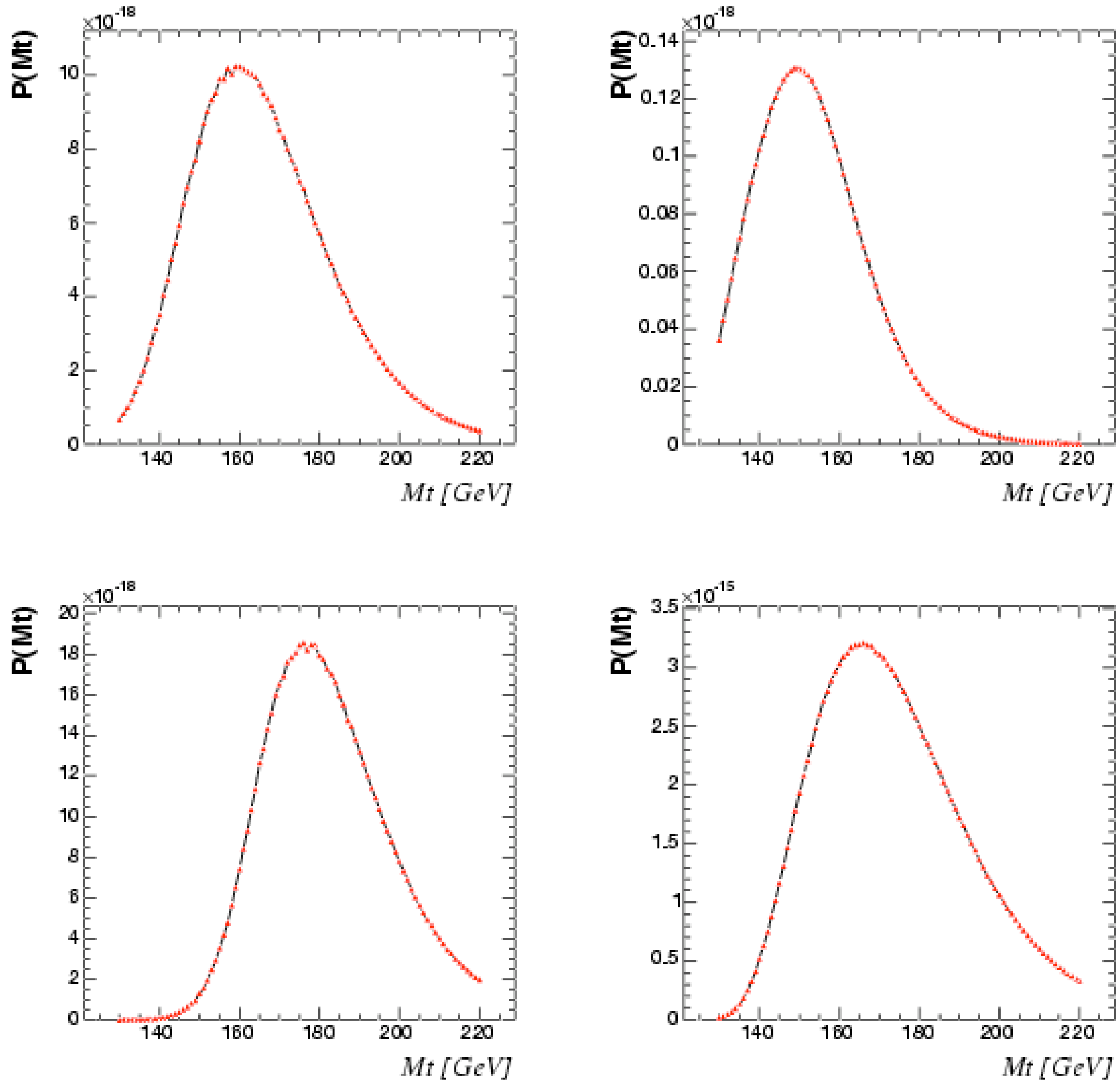
Add 2 integrals for P_T of Zjj system

Alpgen subroutine for Z+2p

Integration with Vegas

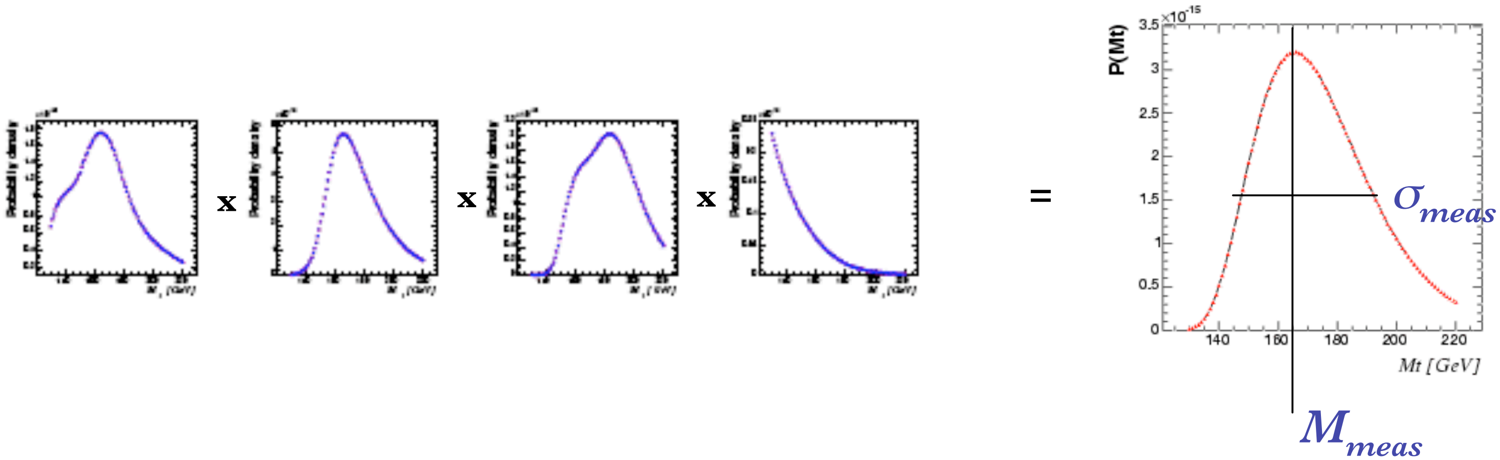
Integration

Four simulated events (Herwig, M_t=180 GeV)



To measure mass, form joint probability.
Final $P(M_t \mid x)$ is a direct calculation.

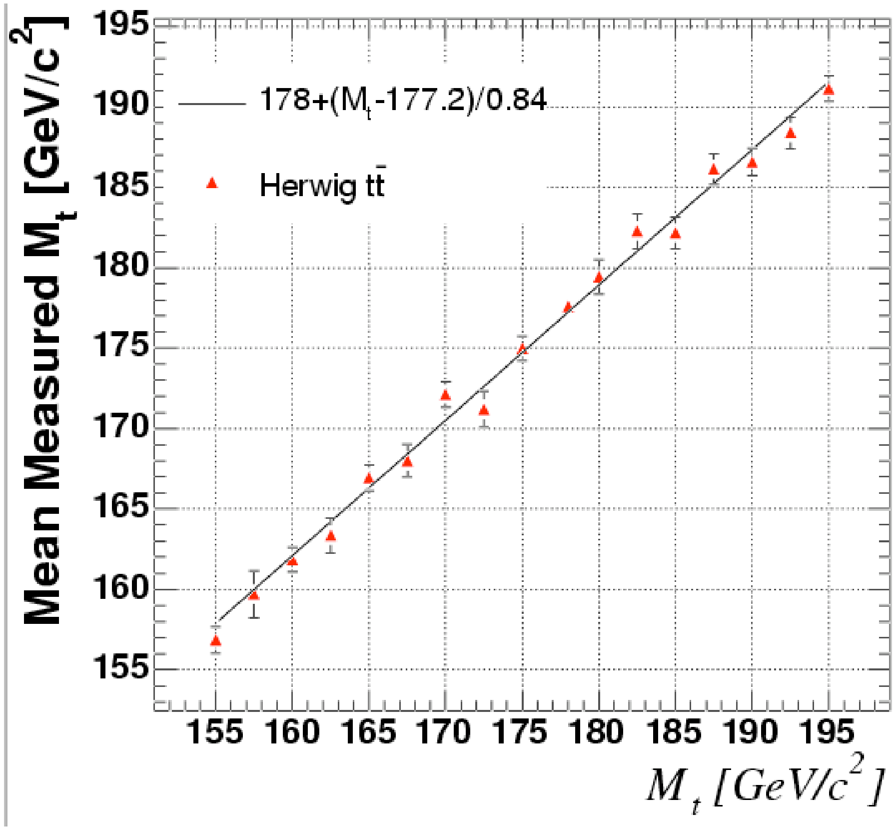
Joint Probability

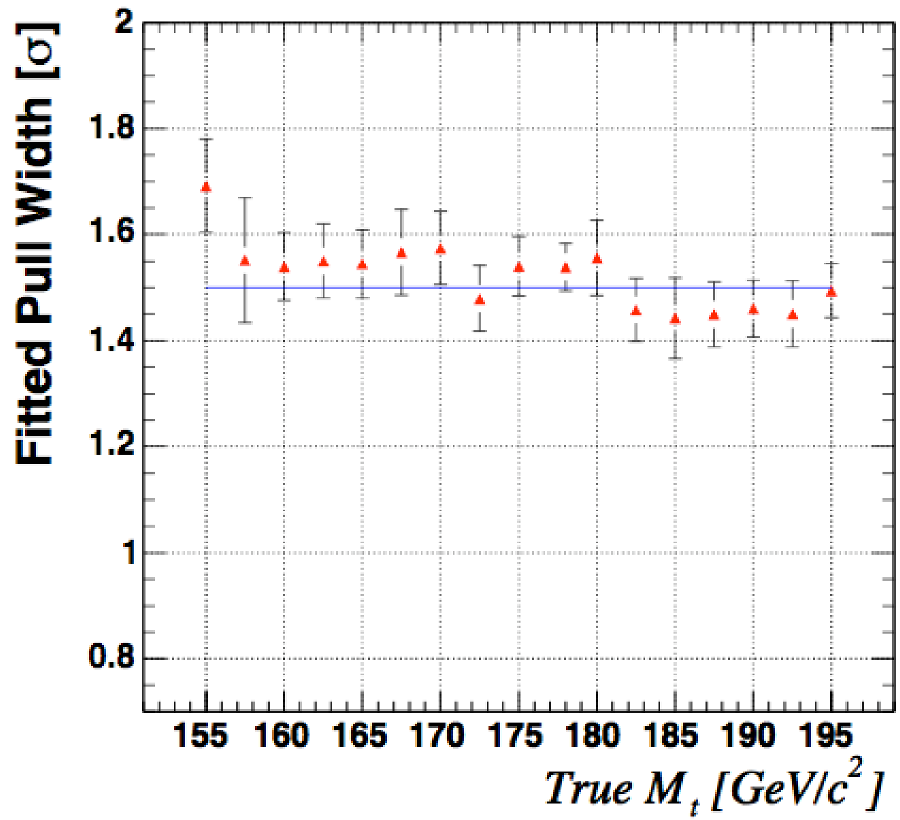


Response = $\langle M_{meas} \rangle$

Pull $= \dfrac{M_{meas} - M_{true}}{\sigma_{meas}}$

Corrections





Response

Linear.

Slope < 1 due to backgrounds.

Error is reduced 15% by P_{bg}

Pull width

Flat.

Width > 1.0 due to assumptions.

Corrections

PW inflated because probability contains assumptions broken to varying degrees.

Assumptions held

Simple simulation: *width = 1.0*

Assemptions broken

Full simulation : *width = 1.5*

+ No background: *width ➡ 1.4*

+ Jets from *b*-quarks: *width ➡ 1.2*

+ Well measured leptons: *width ➡ 1.1*

+ Jet angles well measured: *width ➡ 1.0*

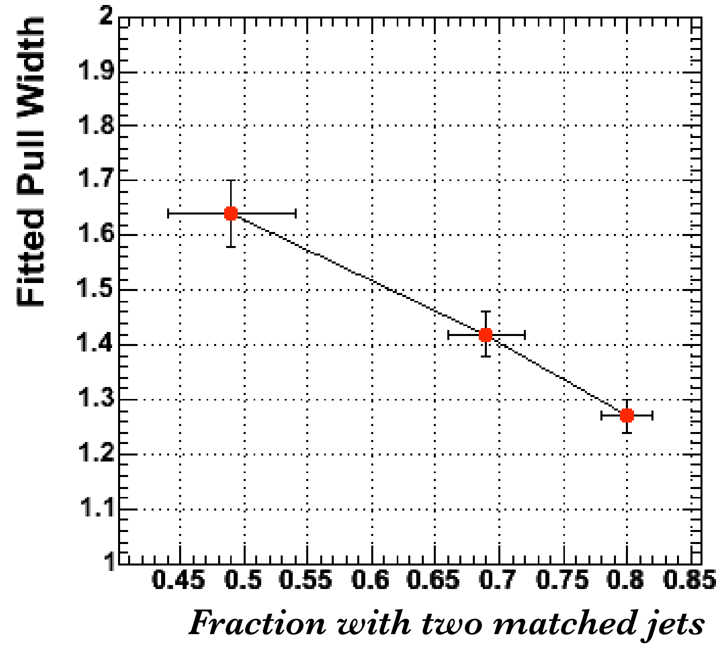
Scale factor for error

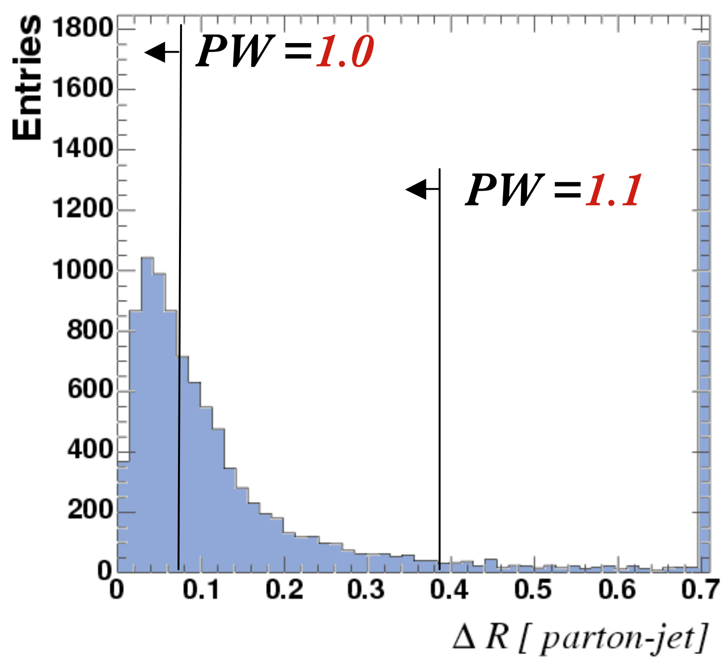
Flat in top mass

Flat in measured statistical error

Insensitive to systematic variations

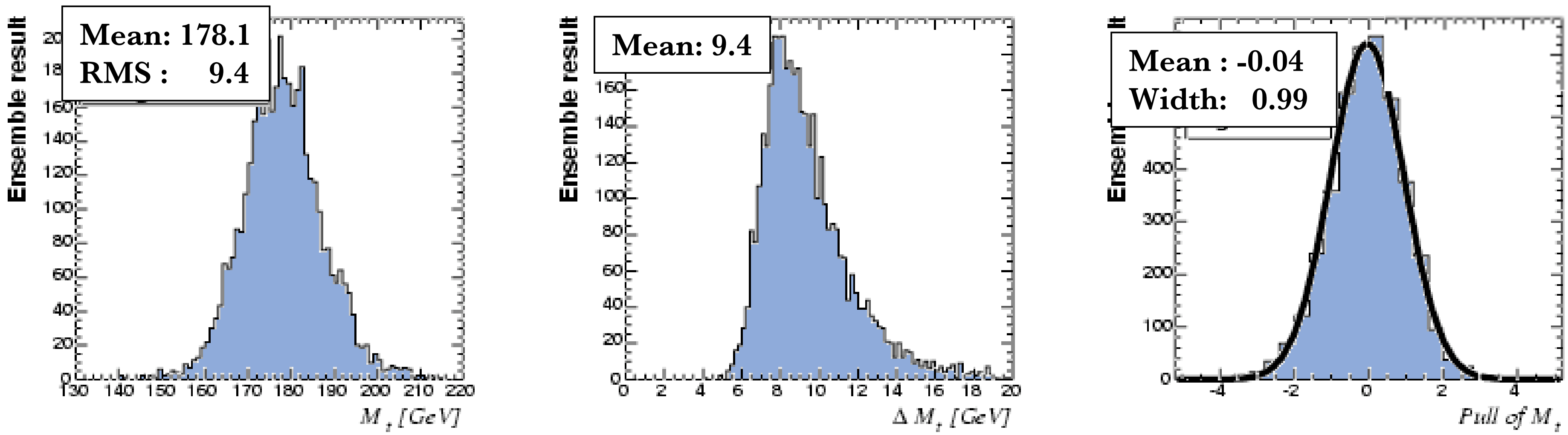
Error on scale factor is ~ 0.03





Behavior at M_t=178 GeV

Behavior is ~ Gaussian, needs only simple corrections.



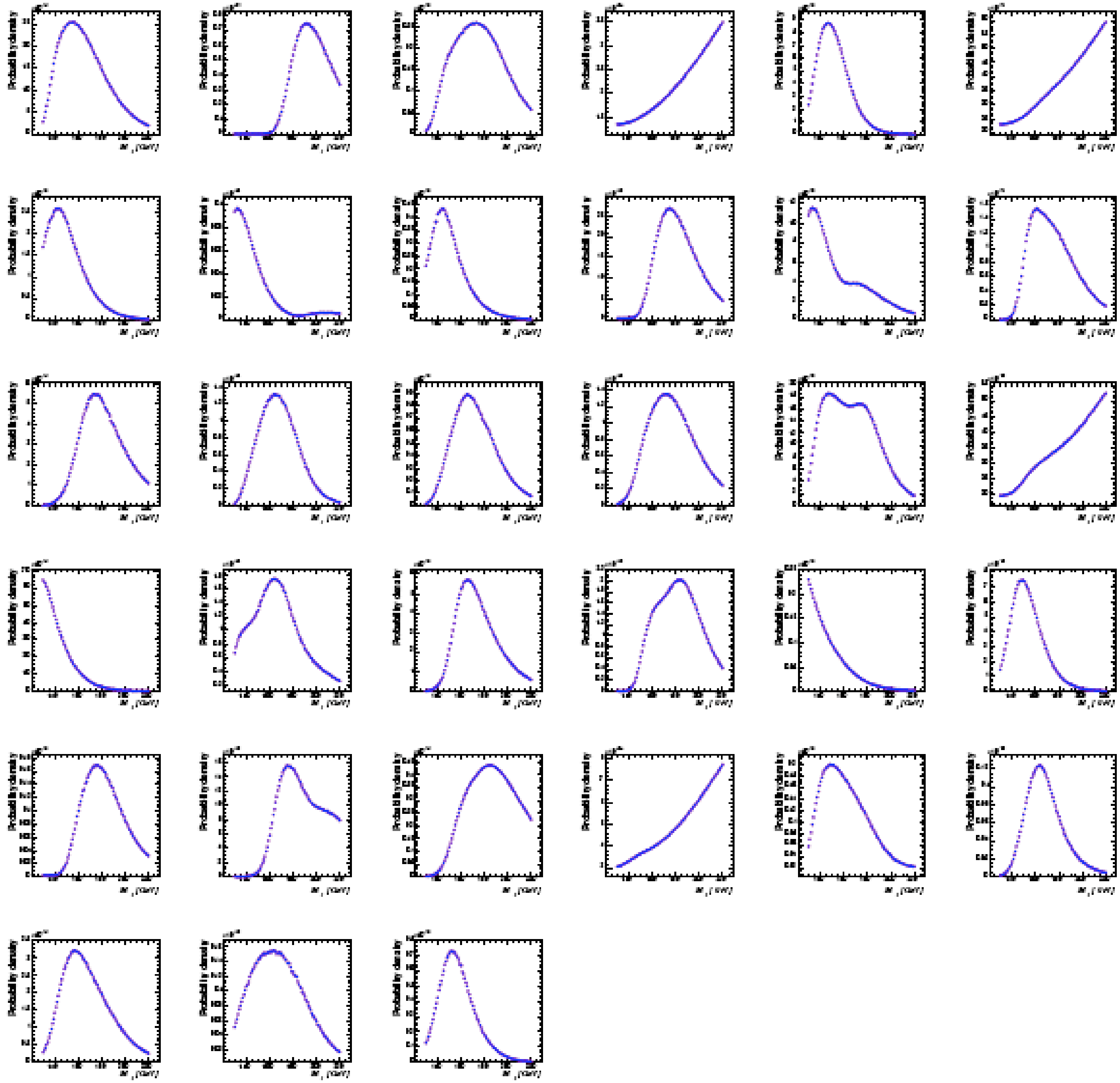
Method	*Mean Error (M_t=178 GeV)*
Matrix Element	**9.4 GeV**
Template: η of ν	**12.8 GeV**
Template: P_z of tt	**14.6 GeV**
Template: ϕ of ν	**14.9 GeV**

Data

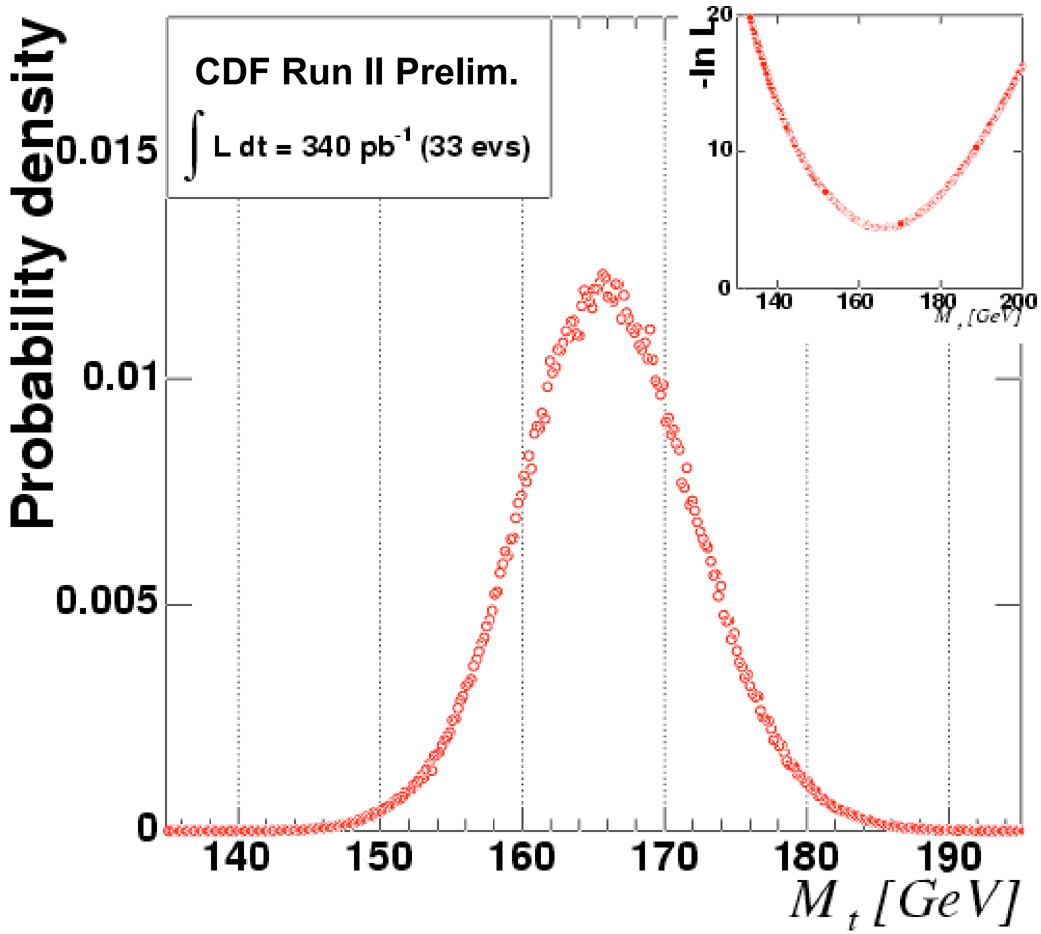
33 candidates

signal and bg probabilities

Range is 130-220 GeV/c^2



Measurement



$$M_t = 165.2 \pm 6.1\ _{stat} \pm 3.4_{syst}\ \mathrm{GeV/c^2}$$

Most precise single dilepton measurement to date.

Prospects for Systematics

Source	*dilepton* $\Delta M_{top}(GeV/c^2)$	*l+jets* $\Delta M_{top}(GeV/c^2)$
Jet Energy Scale	2.6	2.6
Simulation Statistics	1.2	0.3
Parton Distributions	1.1	0.3
Generator	0.8	0.2
Background Shape	0.8	0.5
ISR/FSR	0.7	0.7
Sample Composition	0.7	---
Method	0.6	0.5
B-tagging	---	0.1
Total	3.4	3.0

Summary

Outlook

More sophisticated methods squeeze statistical power out of dileptons

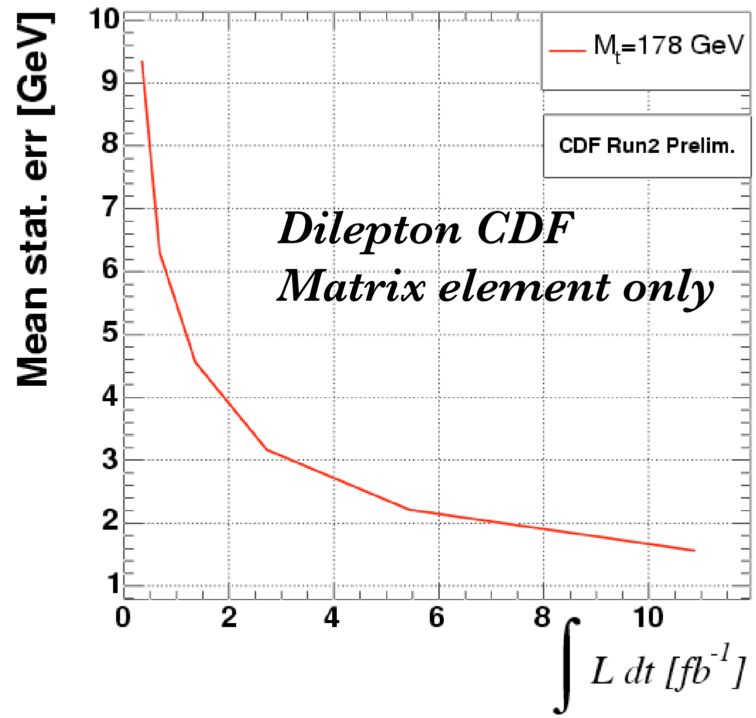
Not yet systematics limited (mean stat error of 2.5 GeV at 4 fb-1)

Better description of ISR will help

Dilepton top mass becomes precision measurement

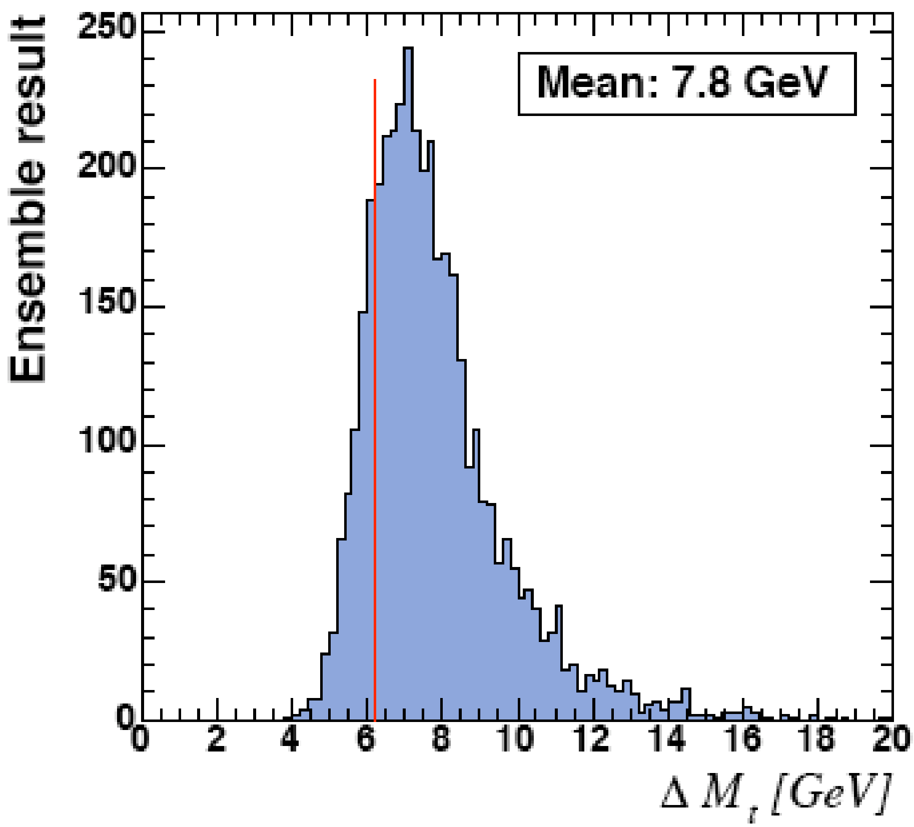
External b-jet calib to help with jet scale - from *Z->bb ?*

Statistical Error



Back up material

Expected sensitivity: Dilepton ME



If M_t= 165 GeV

Full List of Assumptions

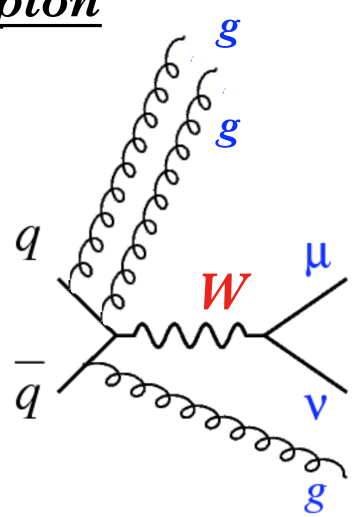
- Initial state
  - No initial state radiation
  - Transverse energy of system is negligible

- Final state
  - Leptons
    - Energy well-measured
    - Direction well-measured

  - Jets
    - Jets arise from *b*-quarks
    - Direction well-measured
    - Energy can be parameterized from parton energy

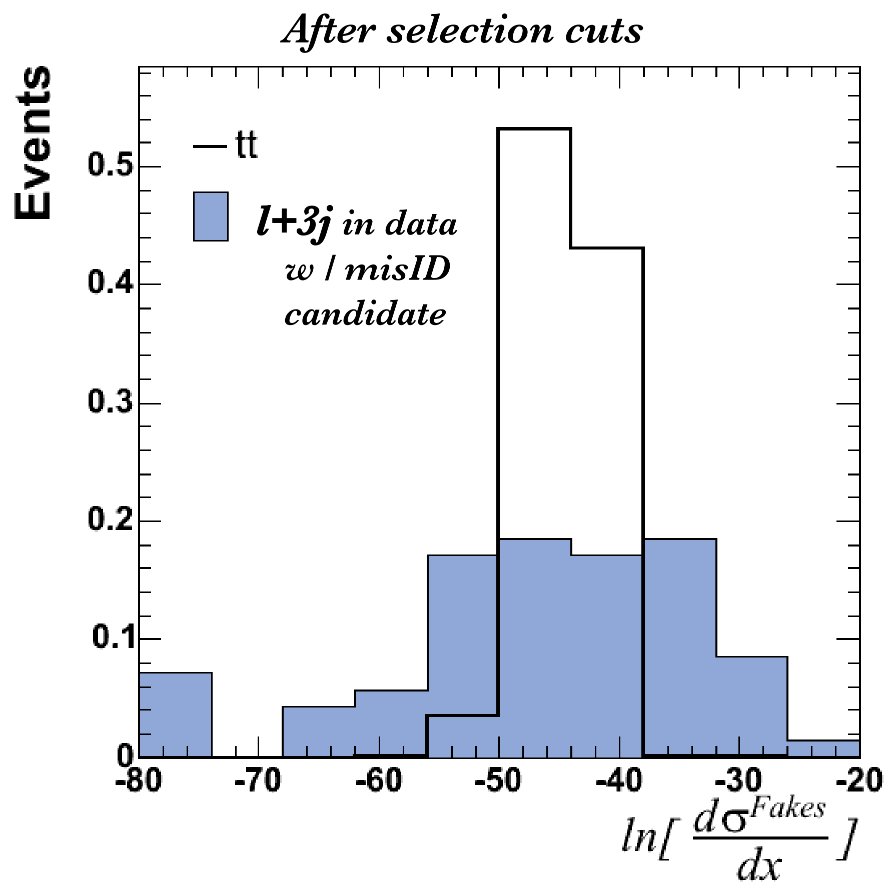
- Assumptions make calculation tractable
  - balance sensitivity with computation time

Mis-ID Lepton



3 unknowns

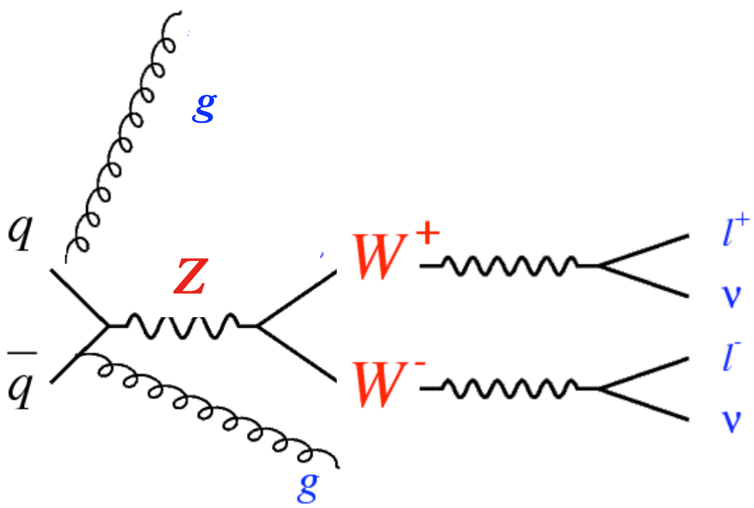
1 parton energy
1 parton energy
3 neutrino *(P components)*
-2 *(P_T conservation)*



Matrix Element & Integrals

Alpgen subroutine for W+3p
Integration with Vegas

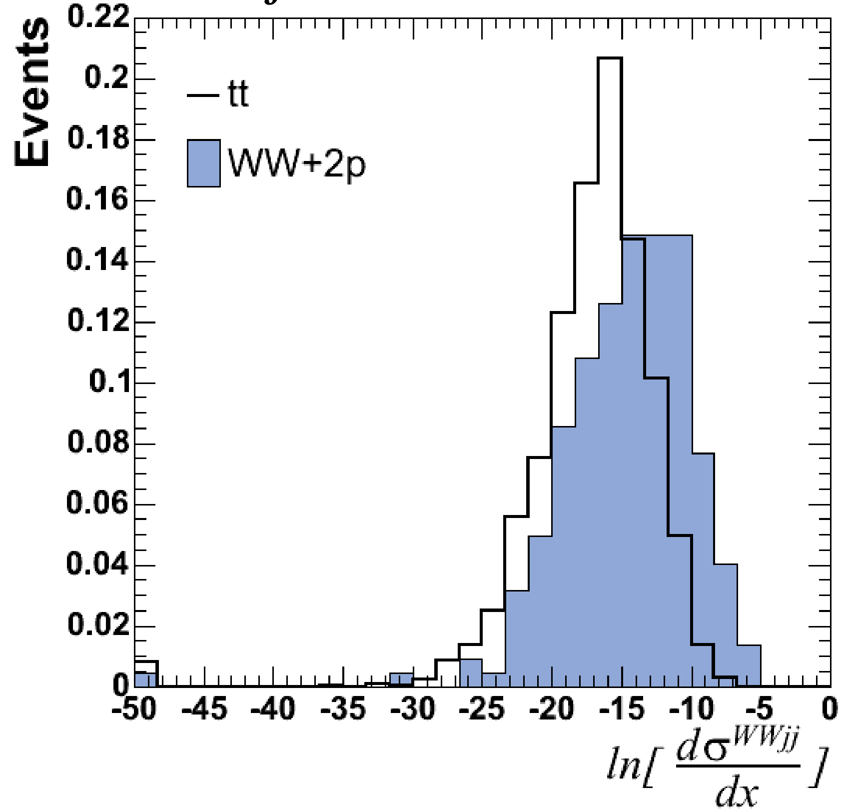
WW+jets



6 unknowns

Parton energy
Parton energy
3 neutrino *(P components)*
3 neutrino *(P components)*
-2 *(P_T conservation)*

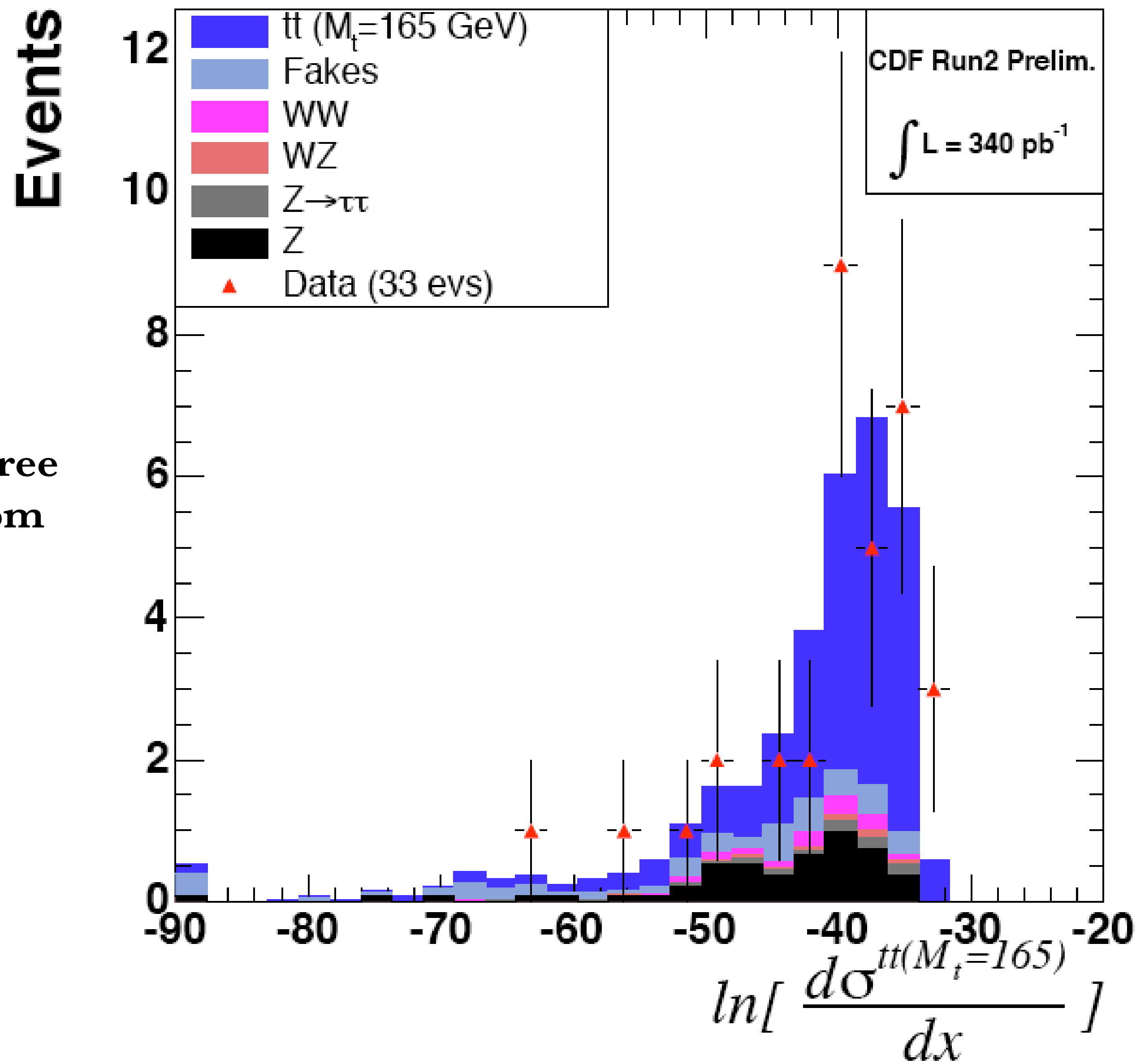
After selection cuts



Matrix Element & Integrals

Alpgen subroutine for WW+2p
Integration with Vegas

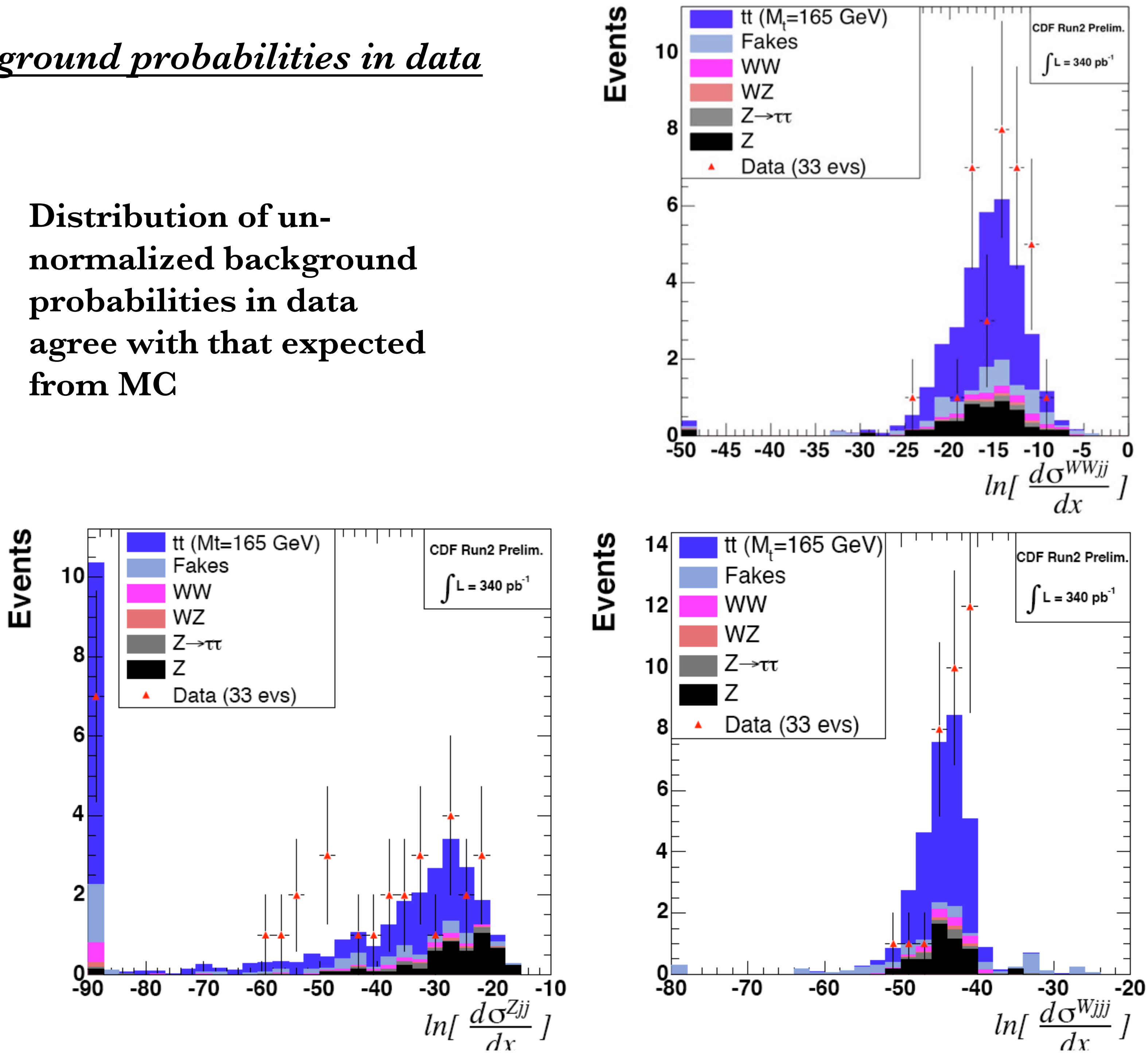
Signal probability in data



Distribution of un-normalized signal probability in data agree with that expected from MC

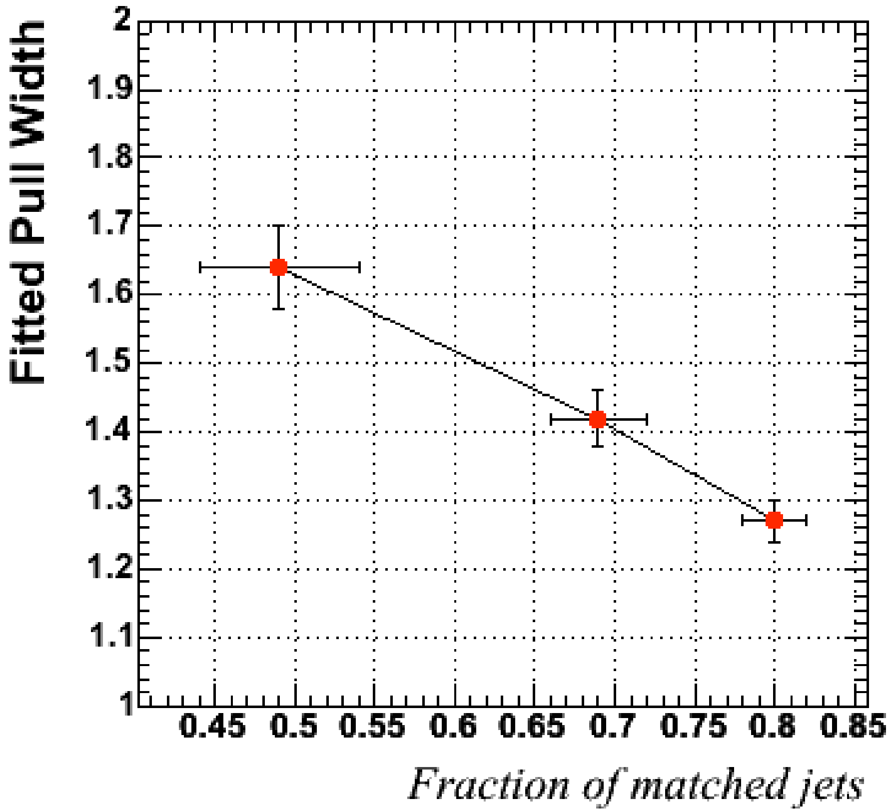
Background probabilities in data

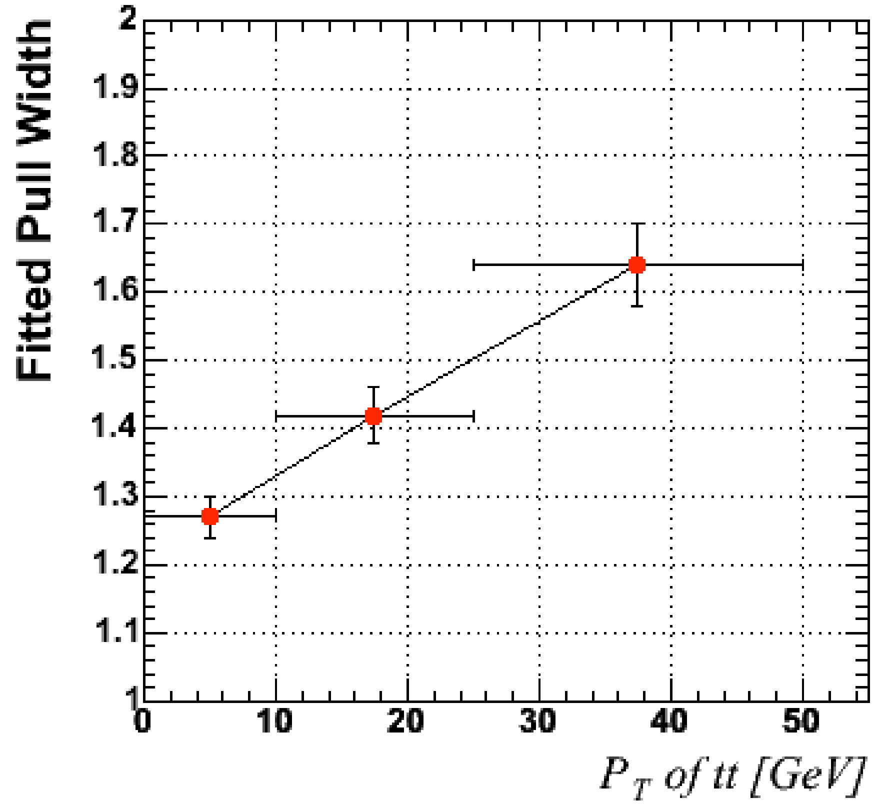
Distribution of un-normalized background probabilities in data agree with that expected from MC



Pull width: mismatched jets

Pull width is affected by wrong jets

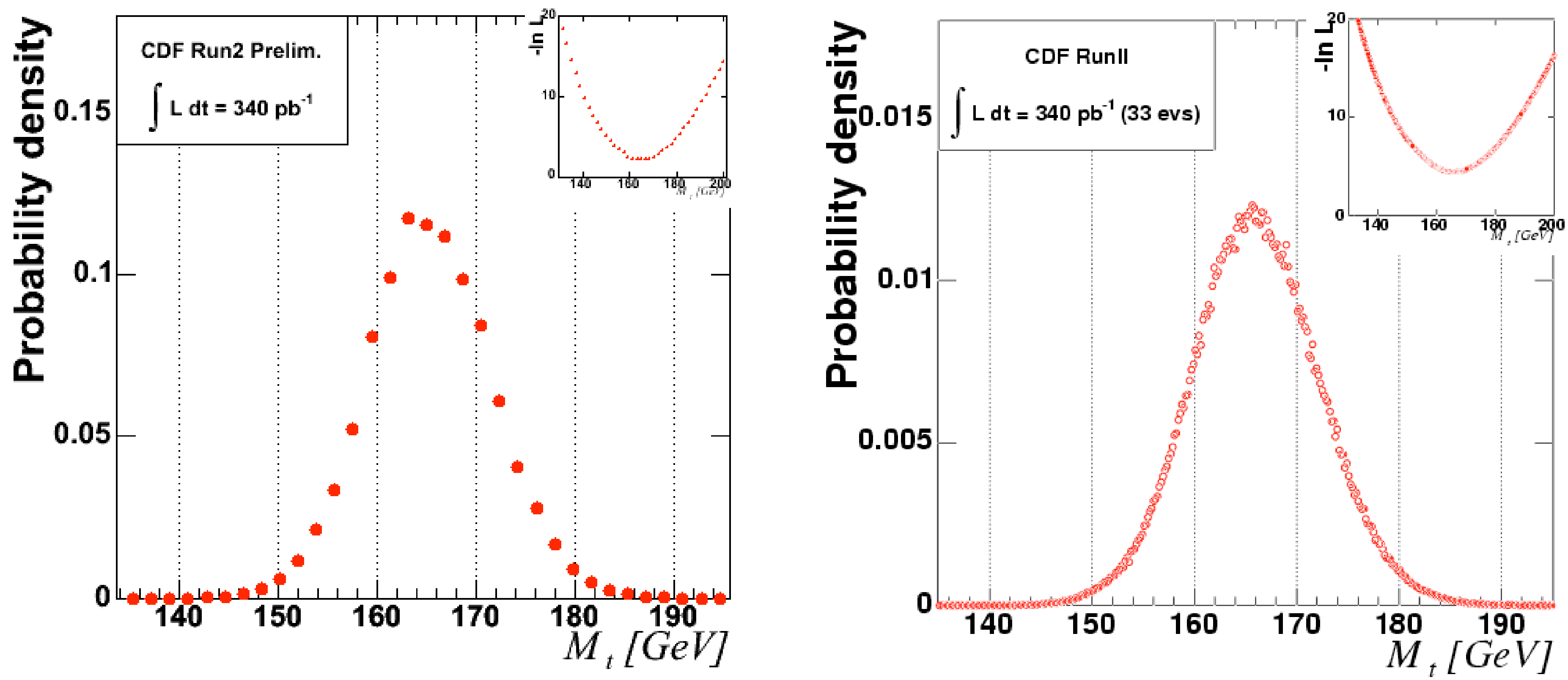




Most wrong jets come from initial state radiation, which can be probed by examining P_T of ttbar

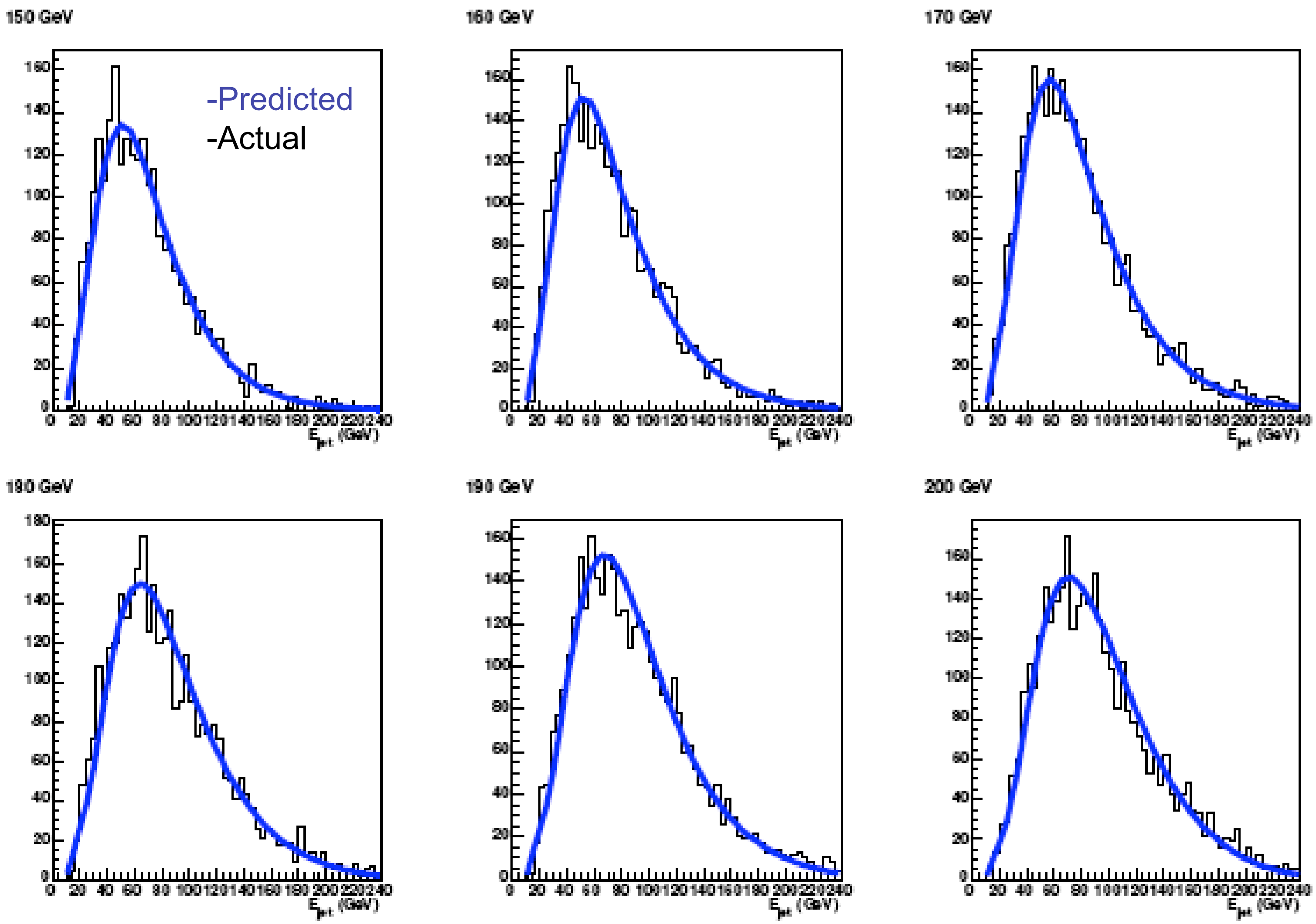
Mass steps refined

We scanned the space in Mt with finer steps to probe the shape:

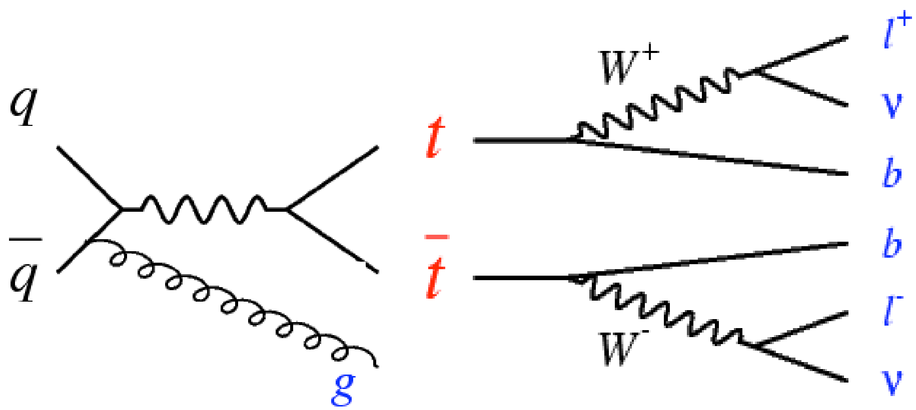


TFS

Transfer functions predict jet energy spectrum at varying top masses.



Future work



Statistical error

-Improve handling of extra jets
(approximates NLO effect)

Systematic error

-Apply jet energy calibration from Z->bb
-Improve sophistication of background modelling